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(54) **SYSTEM AND METHOD FOR DATA READ OF A SYNCHRONOUS SERIAL INTERFACE NAND**

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See application file for complete search history.

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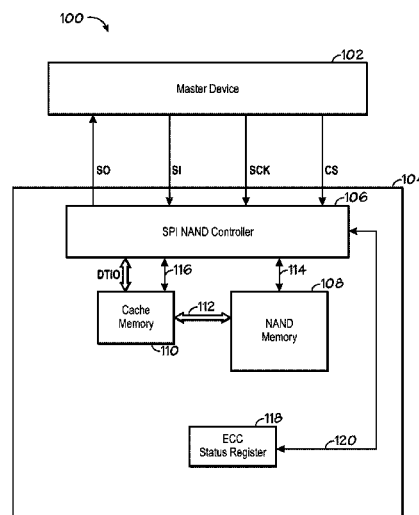
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(57) **ABSTRACT**

A method and system is disclosed for operating a NAND memory device. The NAND memory device is operated by transmitting serial peripheral interface signals from a host to a NAND memory device, whereby the signals are communicated to a NAND memory in the NAND memory device without modifying the signals into a standard NAND memory format. Similarly, a method and system is disclosed for receiving signals from the NAND memory device without modifying the signals from a standard NAND format into a serial format. The system also incorporates error detection and correction techniques to detect and correct errors in data stored in the NAND memory device.

22 Claims, 6 Drawing Sheets



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(2013.01); **G11C 2216/30** (2013.01)
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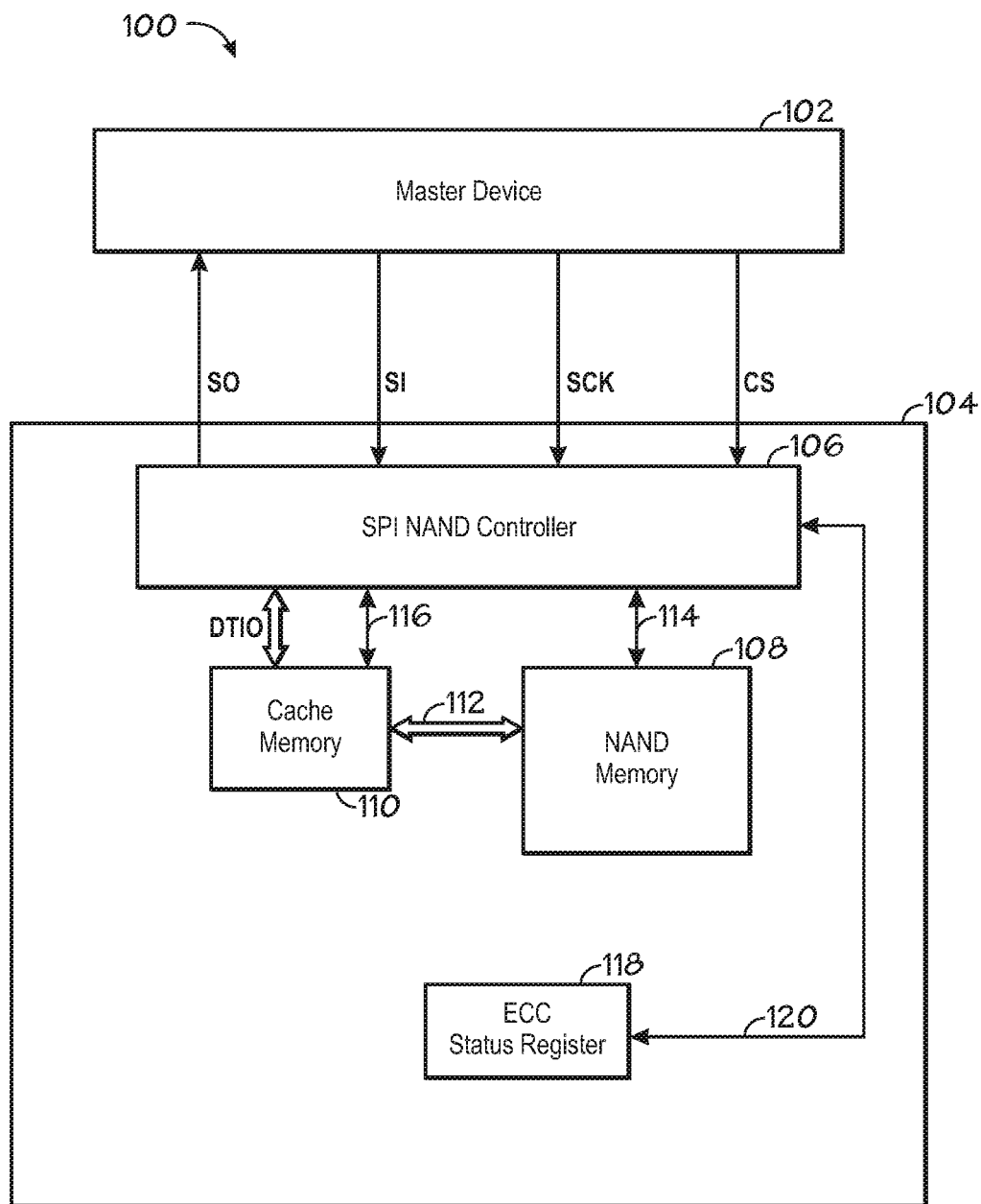


FIG. 1

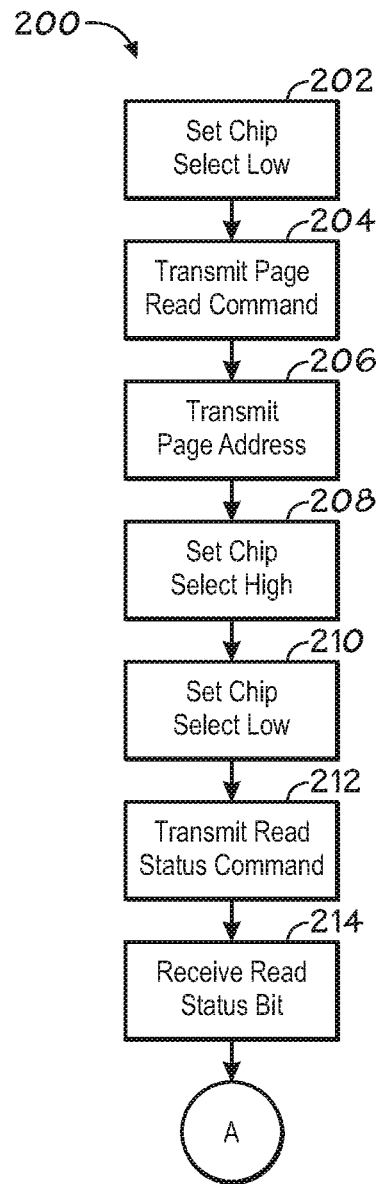


FIG. 2A

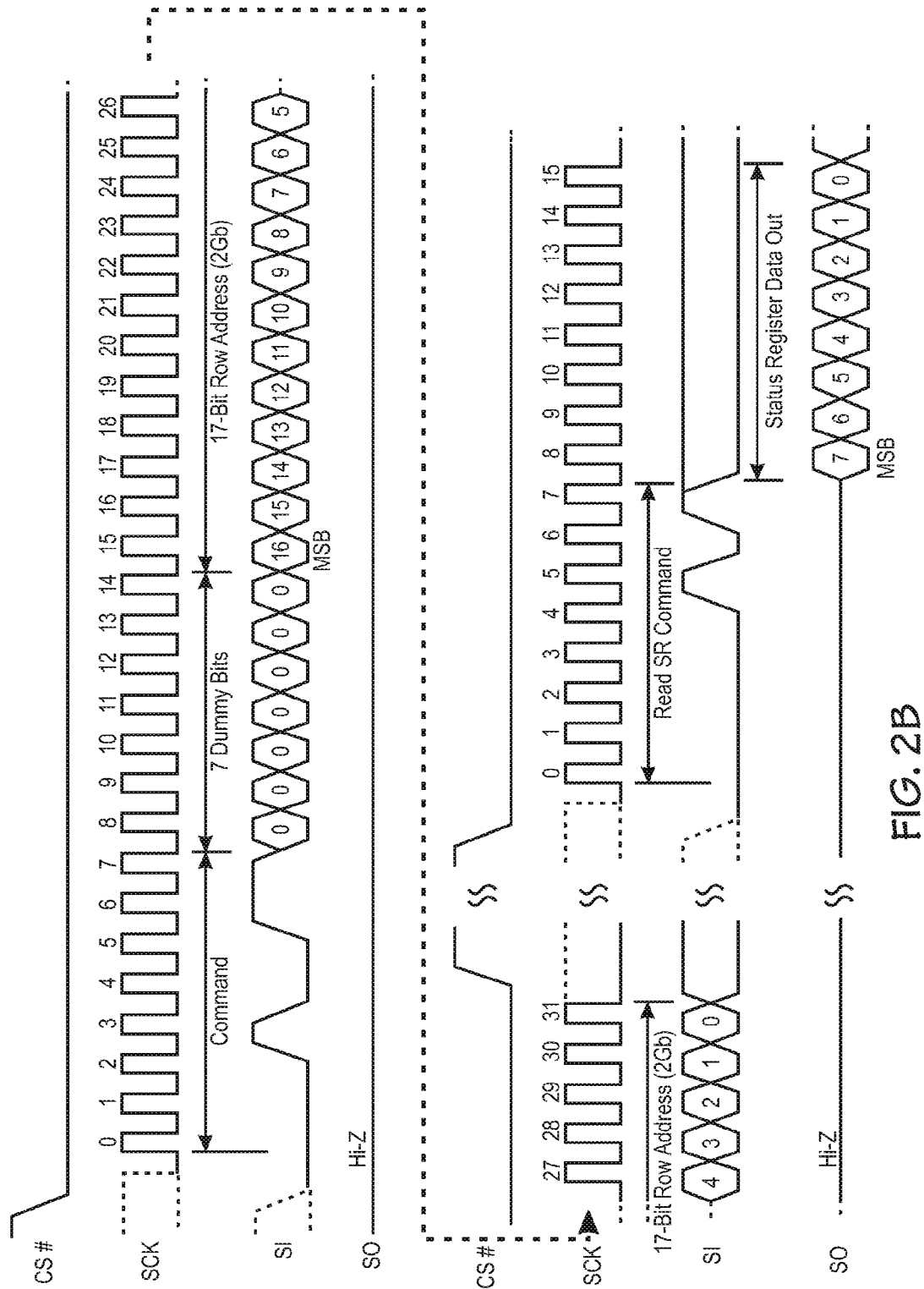


FIG. 2B

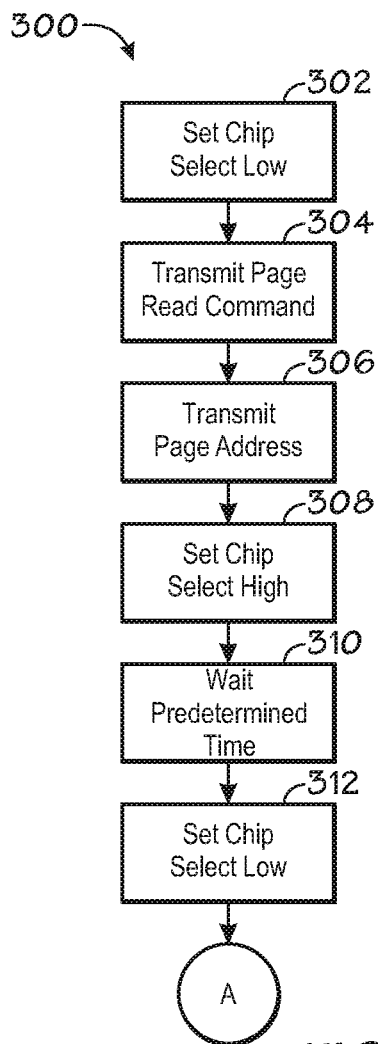


FIG. 3

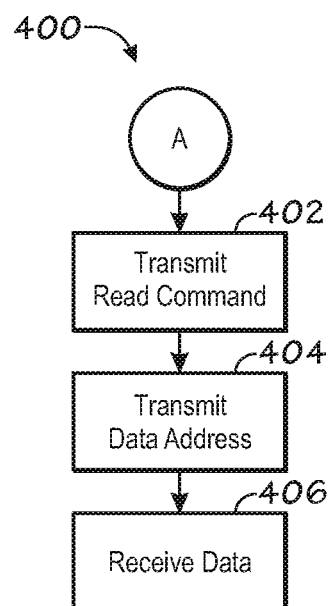


FIG. 4A

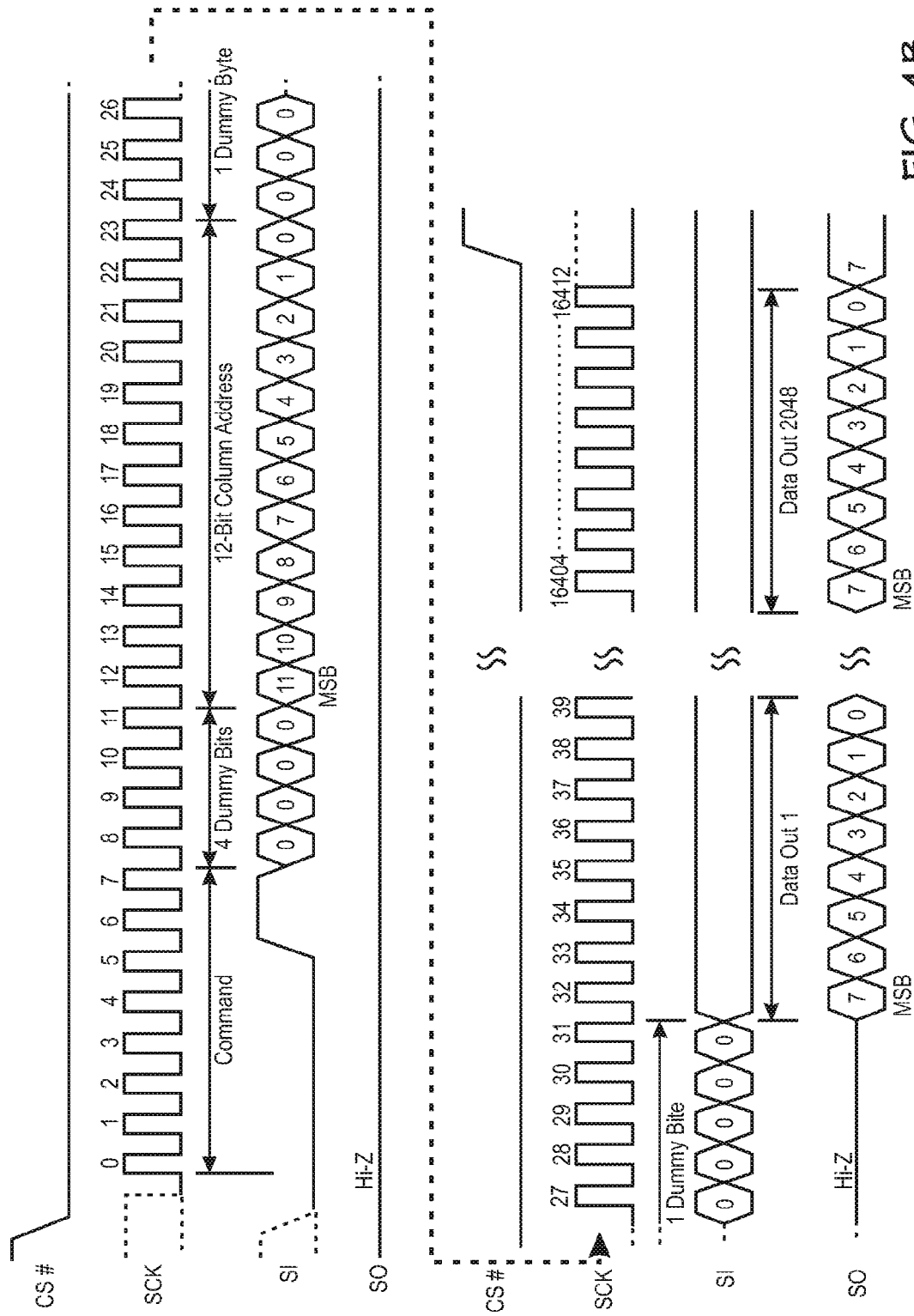


FIG. 4B

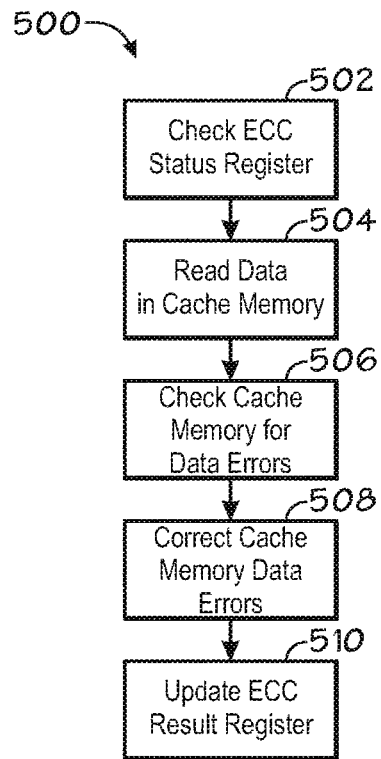


FIG. 5

1

SYSTEM AND METHOD FOR DATA READ OF A SYNCHRONOUS SERIAL INTERFACE NAND

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation of U.S. patent application Ser. No. 13/735,789, which was filed on Jan. 7, 2013, now U.S. Pat. No. 8,694,860, which issued on Apr. 8, 2014, which is a continuation of U.S. patent application Ser. No. 13/357,536, which was filed on Jan. 24, 2012, now U.S. Pat. No. 8,352,833, which issued on Jan. 8, 2013, which is a continuation of U.S. patent application Ser. No. 11/873,833, which was filed on Oct. 17, 2007, now U.S. Pat. No. 8,103,936, which issued on Jan. 24, 2012.

BACKGROUND

1. Field of the Invention

Embodiments of the invention relate generally to a Serial Peripheral Interface for connecting a host device to memory devices.

2. Description of the Related Art

A serial peripheral interface bus (SPI) is a four wire serial communication interface that enables a serial data link between two devices, a master and a slave. It provides support for a low to medium bandwidth network connection between the devices supporting the SPI. Since SPI utilizes only four wires for communication, SPI has become popular for use in systems that require relatively simple IC packages.

The four wires of the SPI include of two control lines and two data lines. The control lines of the SPI include a Chip Select (CS) line and a Serial Clock (SCK) line. While more than one slave device can be connected to the master device, only one slave device may be accessed at any given time. This selection is accomplished by use of the CS line. A CS signal is outputted from the master and allows for activation and deactivation of a slave device by the master device. Every slave device requires a separate CS line for activation. Thus, if ten slave devices exist on the network, there are ten independent chip select lines, one chip select line per slave device.

The master device also provides the serial clock. The SCK is used to clock the shifting of serial data into and out of the master and slave devices. Use of this clock allows SPI architecture to operate in a master/slave full duplex mode, where data is transferred simultaneously from one device acting as a master to a second device acting as a slave.

The data lines of the SPI include a Serial Data In (SI) line and a Serial Data Out (SO) line. The SI line is a data communication line that outputs data from the master device to the slave device. The SO line is a second data communication line used to output data from the slave device to the master device. Both data lines are active only when CS is selected for the specified slave device.

SPI has been used with memory devices such as EEPROM and NOR flash memory. NOR flash memory is a popular and fairly inexpensive memory device. NOR flash memory provides full address and data buses, thereby allowing random access to any memory location. Moreover, typically in NOR flash memory, there is no need for error correction capabilities. This is because the NOR flash memory typically has good reliability without the use of error correction systems. However, a downside of NOR flash memory is that it experiences long erase and write times.

NAND flash memory has faster erase times than NOR flash memory. It also requires smaller chip area per cell than NOR

2

flash memory, leading to greater storage density than that available in NOR flash memory. NAND flash memory also has up to ten times more endurance than conventional NOR flash memory. However, NAND flash memory typically requires some error detection and correction capabilities. Moreover, NAND flash memory does not directly allow for random data access.

Instead of being randomly accessible, like the NOR flash memory, the NAND memory array is made up of many pages of data. To access any specific data location in the array, the corresponding page associated with that data location must be accessed. The page accessed is typically read into a page cache, which can then be accessed for any specific data in the page.

Due to the differences between NOR flash memory devices and NAND flash memory devices, a SPI system configured for use with a NOR flash memory device does not accommodate a NAND flash memory device. Thus, there is a need for a SPI system configured specifically for use with a NAND flash memory device. Embodiments of the invention may be directed to one or more of the problems set forth above.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of a memory device utilizing a serial peripheral interface system in connection with a NAND memory;

FIG. 2A is a flow chart illustrating a method for a master device to access a NAND memory device in accordance with embodiments of the invention;

FIG. 2B is a timing diagram corresponding to the method for a master device to access a NAND memory device in accordance with FIG. 2A;

FIG. 3 is a flow chart illustrating a second method for a master device to access a NAND memory device in accordance with embodiments of the invention;

FIG. 4A is a flow chart illustrating a method for a page read by a master device of a NAND memory device in accordance with embodiments of the invention;

FIG. 4B is a timing diagram corresponding to the method for a page read by a master device of a NAND memory device in accordance with FIG. 4A; and

FIG. 5 is a flow chart illustrating a method for error detection and correction of data stored in a cache memory in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

Turning now to the drawings, and referring initially to FIG. 1, a block diagram depicting an embodiment of a memory system utilizing a serial peripheral interface system in connection with a NAND memory, generally designated by reference numeral **100**, is illustrated. The memory system **100** may be usable in any of a variety of applications, such as, a computer, pager, cellular phone, personal organizer, portable audio player, control circuit, camera, etc. The memory system **100** may include a master device **102** and a slave device **104**. While more than one slave device **104** can be controlled by the master device **102**, for simplicity, only one slave device **104** is illustrated in FIG. 1. In a typical system, the master device **102** operates by sending signals to, and receiving signals from, the slave device **104**.

The communication bus in the memory system **100** between the master device **102** and the slave device **104** is a serial peripheral interface bus (SPI). The operating signals used to communicate between the master device **102** and the

slave device **104** include two control lines and two data lines. The control lines of the SPI include a Chip Select (CS) line and a Serial Clock (SCK) line. The CS signal is outputted from the master device **102** and is received by the slave device **104**, and allows for activation and deactivation of the slave device **104** by the master device **102**. The CS line is typically active low. The SCK signal is outputted from the master device **102** and provides a clock to the slave device **104**. The SCK signal clocks the slave device **104** regardless of whether the slave device **104** is activated by the CS line or not.

The data lines of the memory device include a Serial Data In (SI) line and a Serial Data Out (SO) line. The SI line is a data communication line that carries signals from the master device **102** to the slave device **104**. The SO line is a second data communication line. The SO line is used to output signals from the slave device **104** to the master device **102**. Both data lines are active only when the CS line has been activated, that is, when the CS signal is low.

Control lines CS and SCK, as well as data line SI, carry signals from the master device **102** to the serial peripheral interface (SPI) NAND controller **106**, located in the slave device **104**. Similarly, data line SO carries signals from the SPI NAND controller **106** to the master device **102**. The SPI NAND controller **106** also transmits signals from the data line SI to the NAND memory **108**, via the cache memory **110** along a data input output line (DTIO), and receives signals from cache memory **110** along the DTIO data line. The signals received by the NAND memory **108** are in a modified SPI NAND format. Thus, the signals sent to the NAND memory **108** do not include typical standard NAND format signals such as command latch enable, address latch enable, read enable, write enable, ready/busy, and chip enable. Instead, the signals are transmitted in a modified SPI NAND format. In one embodiment, the modified SPI NAND format signals include specially programmed hexagonal operation signals.

The NAND memory **108** includes a memory cell array which can be broken into blocks. These blocks typically consist of pages of data. Typical groupings include 64 pages of 2048 bytes per page, plus an additional 64 bytes for spare data. Other groupings can include 4096 bytes per page or 8192 bytes per page, with corresponding numbers of page groupings and corresponding additional bytes for spare data. Thus, each page typically has a spare region containing a number of bytes associated with the page. These spare region bytes are normally used for error correction (ECC) purposes. Normally there are between 8 and 256 ECC bytes associated with each page. As described above, the NAND memory **108** typically receives signals from cache memory **110**. That is, the SI line inputs data into the NAND memory **108**, via the cache memory **110** along the DTIO line, without transformation of the data or control signals into standard NAND format.

Data is read out of the NAND memory **108** a full page at a time. The selected page that includes data to be accessed by the master device **102** is read out of the NAND memory **108** and transmitted to the cache memory **110** across data line **112**. Typically, the cache memory **110** is equivalent in size to the page accessed in the NAND memory **108**. The cache memory **110** also includes a small spare region useable to store bytes associated with the page accessed. One embodiment includes a memory cache **110** that holds 2048 bytes of data plus an additional spare storage region of 64 bytes.

Data stored in the cache memory **110** is accessed by the master device **102** through the SPI NAND controller **106**. The cache memory **110** outputs data on the DTIO line to the SPI NAND controller **106** as SPI NAND format data. The SPI NAND controller **106** functions to transmit the output signal along the SO line to the master device **102**. This transmission

of the output signal is based on the input data commands and control signals received from the master device **102** along the SI line.

The SPINAND controller **106** also may communicate with the NAND memory **108** along an access line **114**. This access line **114** can be used to access the pages directly, as well as to access the ECC blocks. Similarly, the SPI NAND controller **106** also may communicate with cache memory **110** along an access line **116**. This access line **116** can be used to access the stored data directly, as well as to access any spare regions. In one embodiment, the access line **116** may be used to transmit and receive error correction and detection information for the cache memory **110**.

The slave device **104** may also include an ECC status register **118**. This ECC status register **118** is accessed by the SPI NAND controller **106** along an access line **120**. Although, in FIG. 1, the ECC status register **118** is shown to be external to the SPI NAND controller **106**, the ECC status register **118** may be incorporated internally into the SPI NAND controller **106**. The ECC status register **118** may also include a group of sub-registers. These sub-registers may include an ECC enable/disable register that allows for optional ECC for the memory device data, an ECC type register that stores the total number of errors detected, or an ECC cache memory result register that stores information regarding the result of any error correction process on the cache memory **110**. The ECC status register **118** may include all of the preceding ECC sub-registers or any combination of the preceding sub-registers.

Turning now to FIG. 2A, a flow chart is illustrated that describes the process **200** undertaken by the master device **102** to transmit a page read command to the slave device **104**. FIG. 2B illustrates a timing diagram corresponding to the flow chart of FIG. 2A. At step **202** of FIG. 2A, the CS line is set to low by the master device **102**, thus selecting the slave device **104** for information transmittal. This is illustrated in FIG. 2B with CS# switching low. In step **204** of FIG. 2A, the master device **102** transmits a page read command to the slave device **104** on the SI line. The page read command operates to initialize the slave device **104** for a data read mode. This is shown in FIG. 2B by the first command illustrated on the SI line. Next, in step **206** of FIG. 2A, the master device **102** transmits a page address to the slave device **104** across the SI line. In one embodiment, dummy bits may be transmitted as a header to the address transmitted to allow for proper byte alignment. For example, if a 17 bit row address is being transmitted, then a 7 bit dummy header may be transmitted so that the entire address length conforms to the slave device data input length requirements. This is illustrated in FIG. 2B by the 7 dummy bits preceding the 17 bit address. Once the page address is transmitted, the master device **102** sets the CS value to high in step **208** of FIG. 2A. This deactivates the communication link between the master device **102** and the slave device **104**. This is illustrated in FIG. 2B with CS# switching high after the addresses are entered.

During the time that CS is set high, the slave device **104** performs internal operations such as accessing the proper page from the NAND memory **108**, transferring the selected page to memory cache **110**, and performing any error detection and correction of data in the memory cache **110**. In step **210** of FIG. 2A, as well as illustrated in FIG. 2B, the CS line is again set to low by the master device **102**, thus selecting the slave device **104** for information transmittal. In step **212** of FIG. 2A, the master device **102** transmits a read status command to the slave device **104** on the SI line. The read status command operates to align the data transmission between the master device **102** and the slave device **104**. This is repre-

5

sented in FIG. 2B by the Read SR Command shown on the SI line. The master device **102** issues a read status command until the slave device **104** sends a status bit on SO that signifies the internal page read operation is complete, as illustrated on the SO line of FIG. 2B. This signals to the master device **102** that the page of the NAND memory **108** accessed by the page read process is stored in the cache memory **110**, and is ready to be accessed by the master device **102**.

In FIG. 3, a flow chart illustrating a second embodiment of the page read process **300** undertaken by the master device **102** to transmit a page read command to the slave device **104**. At step **302**, the CS is set to low by the master device **102**, thus selecting the slave device **104** for information transmittal. In step **304**, the master device **102** transmits a page read command to the slave device **104** on the SI line. The page read command operates to initialize the slave device **104** for a data read mode. Next, in step **306**, the master device **102** transmits a page address to the slave device **104** across the SI line. In one embodiment, dummy bits may be transmitted as a header to the address transmitted to allow for proper byte alignment. For example, if a 17 bit row address is being transmitted, then a 7 dummy bit header may be transmitted so that the entire address length conforms to the slave device data input length requirements. Once the page address is transmitted, the master device **102** sets the CS value to high in step **308**. This deactivates the communication link between the master device **102** and the slave device **104**.

The master device **102** waits a predetermined period of time in step **310** for the slave device **104** to perform its internal operations. During the wait time, the slave device **104** performs internal operations such as accessing the proper page from the NAND memory **108**, transferring the selected page to memory cache **110**, and performing any error detection and correction of data in the memory cache **110**. The predetermined wait time in step **310** is equivalent to the total time of the internal operations of the slave device **104**. This is a predefined number that is based both on the period of the SCK, and on the internal operations to be performed by the slave device. In step **312**, the CS is again set to low by the master device **102**, thus selecting the slave device **104** for information transmittal.

The embodiment described in FIG. 2A and the embodiment described in FIG. 3 both include steps that culminate in the random data read of FIG. 4A. FIG. 4B illustrates a corresponding timing diagram to the flow chart of FIG. 4A. Once the page read process is complete, either because the master device **102** has received a read status bit (FIG. 2A) or because a predetermined time has elapsed (FIG. 3), the master device transmits a data read command on the SI line in step **402** of FIG. 4A. This is also shown in FIG. 4B by the first command illustrated on the SI line. This data read command allows for data to be read from the cache in a random access method. For example, a single byte can be read, a single word can be read, or the entire page can be read starting either at the first byte of the page or starting at any address on the page with a loop-around feature that allows the remainder of the page to be read.

At step **404** of FIG. 4A, the master device **102** transmits the data address to be accessed. In one embodiment, dummy bits may be transmitted as a header to the address transmitted to allow for proper byte alignment. For example, if a 12 bit column address is being transmitted, then a 4 bit dummy header may be transmitted so that the entire address length conforms to the slave device data input length requirements. This is illustrated in FIG. 4B by the 4 dummy bits preceding the 12 bit address on the SI line. In a second embodiment, dummy bits may be transmitted from the master device **102** as

6

a dummy trailer for proper data transmission alignment. This is illustrated in FIG. 4B on the SI line by the dummy byte following the 12 bit address. Once the slave device **104** receives the data address from the master device **102**, the slave device **104** accesses the cache memory **110** and transmits the corresponding data on the SO line, as illustrated in FIG. 4B. This data is received by the master device **102** in step **406** of FIG. 4A.

FIG. 5 represents an embodiment that allows for error detection and correction method **500** for the cache memory **110**. In one embodiment, after step **208** of FIG. 2A, or similarly during step **310** of FIG. 3, the SPI NAND controller **106** performs error detection and correction of the data in the cache memory **110**. At step **502**, the SPI NAND controller **106** checks the ECC status register **118** across access line **120**. The ECC status register **118** includes an ECC enable/disable register. When the ECC enable/disable register is set to disable, no error detection or correction occurs. If, however, the ECC enable/disable register is set to enable, then the SPI NAND controller **106** checks an ECC size register. The ECC size register stores information defining the size of the region on which the ECC algorithm is to be performed. For example, ECC may be performed on each 512 bytes, each 1024 bytes, or any amount of bytes in the cache up to the page size. After the ECC size register is accessed, the SPI NAND controller proceeds to step **504**.

In step **504**, the SPI NAND controller **106** reads the data of the page selected by the master device **102** in the cache memory **110** using the access line **116**. The SPI NAND controller **106** also reads the error correction redundancy bits associated with the selected page using the access line **116**. In one embodiment, redundancy bits are stored with the data bits in the page. In a second embodiment, redundancy bits associated with the data in the selected page are stored in a secondary location in the cache memory **110**.

In step **506**, the SPI NAND controller **106** checks the data read in step **502** by implementing an error detection process. The error detection process uses the redundancy bits corresponding to the data in detecting any errors in the data. If any errors are found, then they are corrected in step **508** using the ECC process. In one embodiment, the error detection and correction techniques make use of linear block encoding and decoding. A further embodiment utilizes specialized sub-classes of binary BCH codes, such as Hamming codes to perform the error detection and correction. A third embodiment utilizes nonbinary BCH codes, such as Reed-Solomon codes to perform the error detection and correction of the data. Upon completion of steps **506** and **508**, the data is sent across access line **116**.

In step **510**, the ECC result register **118** is updated. Preferably, the ECC status register **118** includes sub-registers used to store error detection and correction result information. In one embodiment, updating the ECC result register **118** includes storing the types of error detected and corrected in an ECC type register. For example, values corresponding to no errors, one error detected and corrected, or two errors detected and one error corrected, could be stored in the ECC type register. In another embodiment, step **510** includes updating an ECC NAND memory result register that stores information regarding the result of any error correction process on the cache memory **110**. A further embodiment of step **510** includes updating an ECC NAND memory result register with information regarding the result of any error correction process on both the main portion of the cache memory as well as the spare portion of the cache memory **110**. The informa-

tion updated in the ECC result register **118**, and its sub-registers, is available for access by the master device **102** or by the slave device **104**.

While the invention may be susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and have been described in detail herein. However, it should be understood that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the following appended claims.

What is claimed is:

1. A memory device, comprising:
 - a serial peripheral interface NAND controller configured to be coupled to a Chip Select (CS) line, a Serial Clock (SC) line, a Serial Data In (SI) line, and a Serial Data Out (SO) line;
 - a NAND memory; and
 - a cache memory coupled to the serial peripheral interface NAND controller and the NAND memory, wherein the memory device is characterized in that:
 - the serial peripheral interface NAND controller is further configured to:
 - cause a selected page of data to be transferred from the NAND memory to the cache memory in response to a page read command and a page address received on the SI line; and
 - cause selected data to be accessed from the selected page of data transferred to the cache memory and transmitted along the SO line in response to a data read command and a data address received on the SI line.
2. The memory device of claim 1, wherein the serial peripheral interface NAND controller is configured to cause the selected data to be accessed from the selected page of data transferred to the cache memory when the data address is received after the page address.
3. The memory device of claim 1, wherein the serial peripheral interface NAND controller is configured to send a status bit on the SO line in response to receiving a read status command on the SI line if the selected page of data has been transmitted to the cache memory.
4. The memory device of claim 1, wherein the selected data comprises one of a single byte of the selected page of data, a single word of the selected page of data, or the entire selected page of data.
5. The memory device of claim 1, wherein the serial peripheral interface NAND controller is configured to receive dummy bits as a header to the page address.
6. The memory device of claim 1, wherein the serial peripheral interface NAND controller is configured to receive dummy bits as a header to the data address.
7. The memory device of claim 1, wherein the serial peripheral interface NAND controller is configured to receive dummy bits as a trailer to the page address.
8. The memory device of claim 1, wherein the memory device is configured to read the selected page of data out of the NAND memory and transfer the selected page of data to the cache memory during a time that a signal on the CS line is inactive.
9. The memory device of claim 1, comprising an error correction status register coupled to the serial peripheral interface NAND controller, wherein the error correction status register is configured to store error correction enable and disable information.
10. The memory device of claim 1, comprising an error correction status register coupled to the serial peripheral

interface NAND controller, wherein the error correction status register is configured to store information defining the size of the region on which the an error correction algorithm is to be performed.

11. A method for accessing a serial peripheral interface NAND memory device, comprising:

- receiving a page read command on a Serial Data In (SI) line of the serial peripheral interface NAND memory device;
- receiving a page address on the SI line of the serial peripheral interface NAND memory device,

- causing, via a serial peripheral interface NAND controller of the serial peripheral interface NAND memory device, a selected page of data to be:

- read out of a NAND memory of the serial peripheral interface NAND memory device; and

- transmitted to a cache memory of the serial peripheral interface NAND memory device in response to the page read command and a page address received on the SI line; and

- causing, via the serial peripheral interface NAND controller of the serial peripheral interface NAND memory device, selected data of the selected page of data to be read from the cache memory in a random access method.

12. The method of claim 11, comprising transmitting the selected data on a Serial Data Out (SO) line in response to a data read command and data address received on the SI line.

13. The method of claim 12, comprising receiving the data address subsequent to receiving the page address.

14. The method of claim 12, comprising transmitting a status bit on the SO line in response to receiving a read status command on the SI line if the selected page of data has been transmitted to the cache memory.

15. The method of claim 11, wherein the selected data comprises one of a single byte of the selected page of data, a single word of the selected page of data, or the entire selected page of data.

16. The method of claim 11, comprising checking the selected page of data by an error correction process.

17. A memory device, comprising:

- a serial peripheral interface NAND controller configured to receive an activate signal, a timing signal, and a serial data in signal, wherein the serial peripheral interface NAND controller is further configured to transmit the serial in data signal without translation into standard NAND format.

18. The memory device of claim 17, comprising a NAND memory coupled to the serial peripheral interface NAND controller and configured to receive the serial data in signal transmitted from the serial peripheral interface NAND controller.

19. The memory device of claim 18, comprising a cache memory coupled to the serial peripheral interface NAND controller and the NAND memory, wherein the cache memory is configured to receive a selected page of data from the NAND memory in response to a page read command and a page address being received at the serial peripheral interface NAND controller.

20. The memory device of claim 19, wherein the cache memory is configured to allow selected data of the selected page of data to be read from the cache memory in a random access method.

21. The memory device of claim 20, wherein the serial peripheral interface NAND controller is configured to transmit the selected data on a Serial Data Out (SO) line in response to a received data read command and data address.

22. The memory device of claim 19, wherein the serial peripheral interface NAND controller is configured to perform error correction on data stored in the cache memory.

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